II. Functional Components of a Detector System

Large detector systems may consist of several subsystems especially designed to perform specific functions, for example

- position sensing (tracking)
- total energy measurement (calorimeters)
- timing
- particle identification

Although these subsystems may look very different and use radically differing technologies, they all tend to comprise the same basic functions:

1. Radiation deposits energy in a detecting medium.

   The medium may be gas, solid or liquid.

   In a tracking detector one wishes to detect the presence of a particle without affecting its trajectory, so the medium will be chosen to minimize energy loss and particle scattering.

   Conversely, if one wishes to measure the total energy (energy spectrometry or calorimetry), the absorber will be chosen to optimize energy loss (high density, high Z).

2. Energy is converted into an electrical signal, either directly or indirectly. Each detected particle will appear as a pulse of electric charge.

   Direct conversion:
   incident radiation ionizes atoms/molecules in absorber, creating mobile charges that are detected.
   (ionization chambers)

   Indirect conversion:
   incident radiation excites atomic/molecular states that decay by emission of light, which in a second step is converted into charge.
   (scintillation detectors)

   The primary signal charge is proportional to the energy absorbed.

   Some typical values of energy required to form a signal charge of 1 electron:

gases	30 eV
semiconductors	3 to 10 eV
scintillators	20 to 500 eV

   In neither of these schemes is the signal charge available instantaneously. In a scintillation detector the pulse duration is determined by the decay time of the optical transitions, in an ionization chamber the charges must move to the electrodes to obtain the full signal.

   Typical pulse durations: 1 ns – 10 μs

3. The electrical signal is amplified.

    a) electronic circuitry

    b) gain by secondary multiplication

    primary charge is accelerated to sufficient energy for it to liberate additional charge carriers by impact ionization.

    Examples: proportional chambers
    avalanche photodiodes
    photomultiplier

Both techniques may introduce significant random fluctuations (noise).

Ideally, a gain stage would increase only the magnitude of the pulse, without affecting its time dependence.

This ideal behavior is never strictly realized in practice, as it would require amplifiers with infinite bandwidth.

However, this is not a severe limitation, as in many applications it is quite acceptable and even desirable to change the pulse shape.

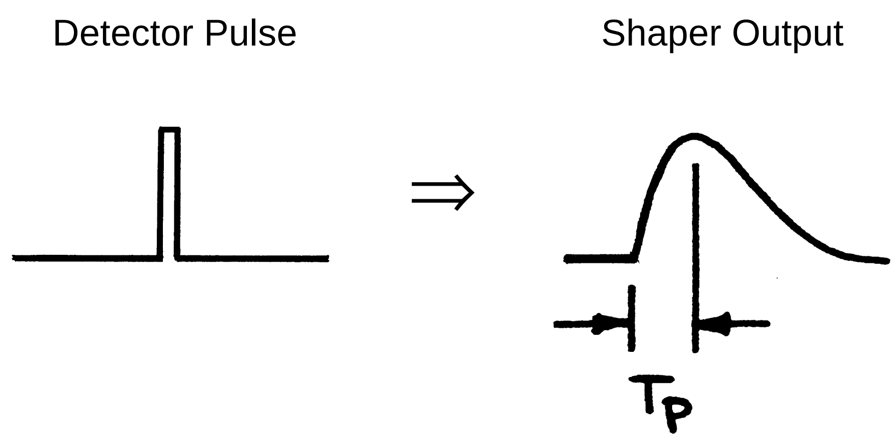
4. Pulse shaping
(not always necessary, but always present in some form)

The time response of the system is tailored to optimize the measurement of signal magnitude or time and the rate of signal detection.

The output of the signal chain is a pulse (current or voltage) whose area is proportional to the original signal charge, i.e. the energy deposited in the detector.

Typically, the pulse shaper transforms a narrow detector current pulse to

a broader pulse
(to reduce electronic noise),
with a gradually rounded maximum at the peaking time T_P
(to facilitate measurement of the amplitude)

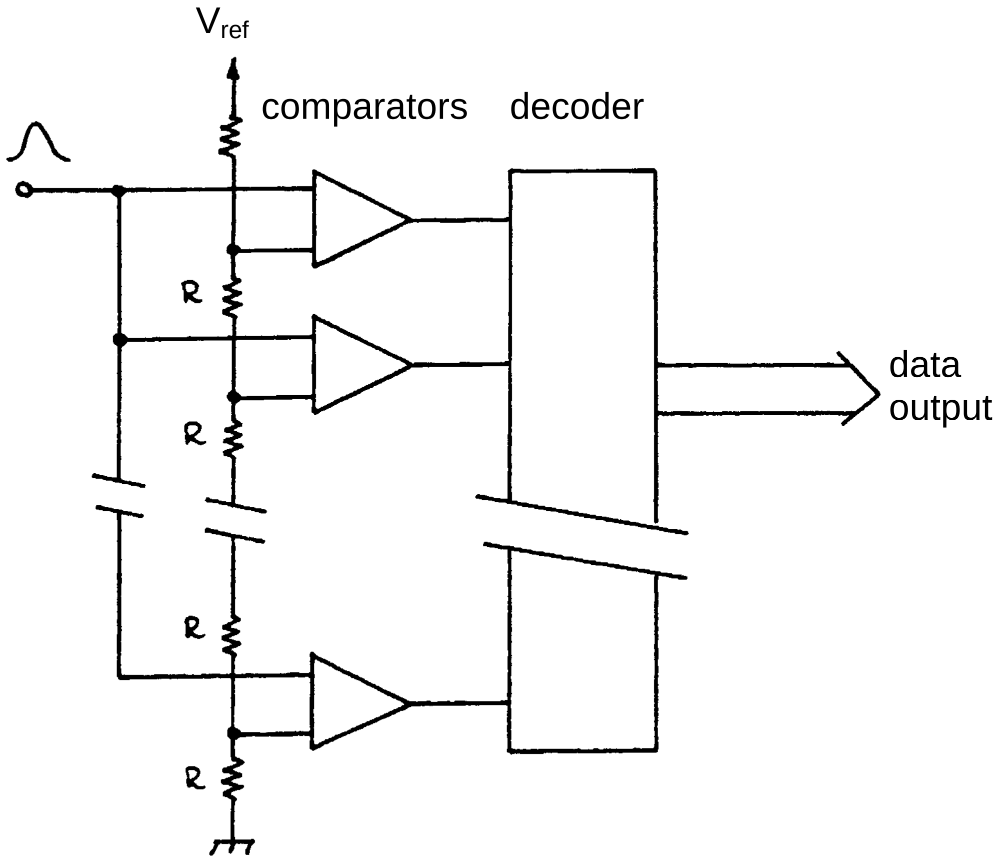


If the shape of the pulse does not change with signal level, the peak amplitude is also a measure of the energy, so one often speaks of pulse-height measurements or pulse height analysis. The pulse height spectrum is the energy spectrum.

5. Digitization of

a) signal magnitude
(analog-to-digital converter, viz. ADC or A/D)

Example:



The input signal is applied to n comparators in parallel. The switching thresholds are set by a resistor chain, such that the voltage difference between individual taps is equal to the desired measurement resolution.

In the presence of a signal all comparators with threshold levels less than the signal amplitude will fire. A decoder converts the parallel bit pattern into a more efficient form, for example binary code.

This type of ADC is fast, but requires as many comparators as measurement bins. Other converter types provide higher resolution and simpler circuitry at the expense of speed.

b) time difference between the detected signal and a reference signal
(time-to-digital converter, TDC)

The reference signal can be derived from another detector (as in TOF-PET) or from a common system clock, the crossing time of colliding beams, for example.

Circuit implementations include schemes that count “clock ticks” in fully digital circuitry or combine time-to-amplitude and amplitude-to-digital conversion in mixed analog-digital arrangements.

In complex detector systems the individual digitized outputs may require rather complex circuitry to combine the signal associated with a specific event and “package” them for efficient transfer.